PART 1: FUELS AND MATERIALS TEST STATION

Author: Mahlon Wilson, October 2002

The Fuels and Materials Test Station (FMTS) is a facility where samples may be irradiated in intense fields of neutrons and/or protons. The facility is designed to allow versatility in the configuration of samples and targets, and choice of coolant.

The Facility

Test Station Arrangement

Samples are mounted in a holder that provides positioning and temperature control. The sample holder surrounds a target that absorbs the 800-MeV LANSCE proton beam and produces several neutrons per incident proton. The sample holder and target are mounted on the bottom of a stalk that is lowered into a vacuum tank filled with shielding (Fig. 1). The proton beam enters the side of the tank and strikes the target. Additional shielding around the tank contains activated support systems and provides personnel protection.

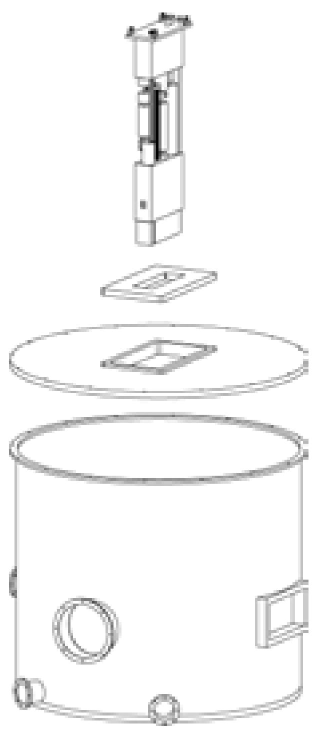


Fig. 1. Exploded view of FMTS stalk and vacuum vessel.

The test station is located at the western end of LANSCE Experimental Area A, at the position historically occupied by Target Cell A-1. The existing hot cells will be used for sample retrieval.

Preliminary analysis of targets, samples, cooling, shielding, and support equipment has been performed and is described below. Several dimensions are provided that appear at this stage to be reasonable, but must be reanalyzed as the project proceeds. Known constraints on parameters are mentioned to alert future designers.

Ref: This proposal has many similarities with an earlier one entitled *LANSCE 800-MeV Isotope Production Facility, A Preconceptual Design*, November 1999.

The Stalk Assembly

The stalk assembly serves the function of positioning the target and sample holder reliably on the beam centerline. It will provide sufficient upward shielding so that the top of the stalk may contain elastomer components and may be handled when the beam is off. The stalk assembly will be equipped with cooling, instrumentation, control power, heating power, beam diagnostics, and sample removal means, as required (Fig. 2).

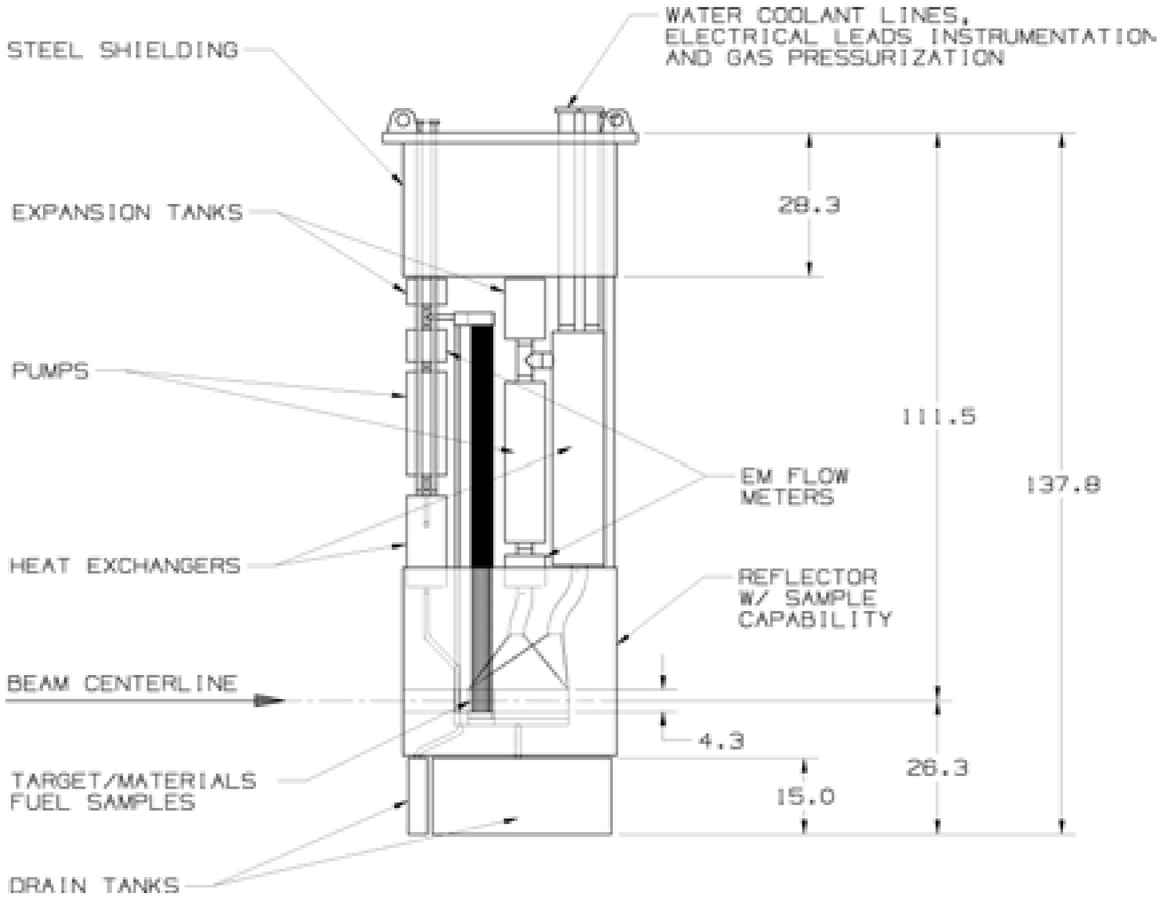


Fig. 2. FMTS stalk concept.

The target and the sample holder may be cooled by separate systems and by different coolants; PbBi, Na, He, and water have been considered. The stalks have been sized to contain the components of the two primary coolant systems when using PbBi or sodium for cooling the samples and the target. This allows the liquid metal systems to be sealed and conditioned elsewhere, prior to irradiation. This stalk configuration should be the largest necessary for all the cooling options.

Secondary cooling for a PbBi system could be water, and for a Na system might be via a NaK loop to an air-cooled radiator located outside the tank.

For water and He cooling, it is probably more cost-effective to locate the bulk of the cooling system components outside the tank, buried within the external shielding. This allows the expensive components to be reused and only a few feet of pipe located within the stalk, resulting in a simpler stalk.

The dimensions of the stalk impact all facets of the facility. It must be short enough to allow removal by the building crane (40-ft hook height above the floor). It must be tall enough to accommodate the target/sample holder, cooling system components, dump tanks, and adequate shielding. It must be wide enough to accommodate the target/sample holder, and cooling systems. It must be long enough so that most of the beam power is removed by stalk-mounted components. The intent is that the components that are the most radiation-damaged are removed with the stalk, leaving behind only items having a very long lifetime. However, the width and length should be minimized as they greatly impact the weight of the stalk (disposed material), and the size and weight of a cask should one be considered in planning for stalk removal (crane limit is 30 tons).

Preliminary sizing, based upon the assumption that separate PbBi cooling systems service the sample holder and the target, and that individual samples may be removed, result in a stalk having a minimum width of 12 inches and a length of 42 inches. This reference stalk is 11.5 ft tall, with the beam passing through the target 9 ft-3.5 inches below the top of the top flange. Six inches of reflector material and two PbBi dump tanks are located below the target.

The dimensions for the target-cooling components of the reference stalk are identical to those of the Russian-constructed Target Circuit TC-1 intended for use at A-6. The sample cooling pump and heat exchanger were visually scaled down to about one-fourth the size of the target components.

Reference: The neutronics calculations were performed by Karen Cozine, LANSCE-12, 7-8843. The heat transfer and fluid flow calculations were performed by Gordon Willcutt, D-10, 7-5869. The assembly drawings were made by Walt Chaves, ESA-DE, 5-2223.

The Vacuum Tank

The primary purpose of the vacuum tank is to exclude air from the vicinity of the target. This allows the proton beam to impinge on the target without having to traverse a separate vacuum window. Shielding within the tank reduces the neutron and proton fluxes sufficiently that the air surrounding the tank does not become activated, eliminating radioactive air emissions.

The shielding within the tank is also sized to reduce activation to the tank walls to permit personnel access to the top of the stalk and the outside of the tank when beam is off, and to allow personnel entry into the tank after removal of the internal shielding.

Preliminary calculations indicate that 5 ft of steel east of the target, and 4 ft in all the other directions should protect the tank and the surrounding air. Minimum tank diameter calculation is 4 ft of shielding west of the target plus 5 ft east plus 3.5 ft for the target = 12.5 ft. A diameter of 15 ft was chosen to provide space to accommodate a realistic mechanical design for the shielding, vacuum pumping gaps, and seismic restraint.

The elevation of the Area A floor (8-ft-thick magnetite concrete) is 6967 ft above sea level. The beam elevation is 6972 ft, or 5 feet above the floor. This locates the target sufficiently close to the floor that special consideration needs to be given to the shielding below the target, especially the PbBi configuration wherein the dump tanks may reside below the target. (The dump tanks are empty during operation, affording no downward shielding.) Materials such as tungsten, which is more effective as neutron shields than steel, may be required below the target.

The vacuum tank should rest on the concrete floor to get its steel floor as far as possible below the target to reduce activation.

*Note: The 5 ft beam elevation is historical as it was adequate to accommodate the targets and magnets envisioned for all the beam lines. Lowering the beam line reduces the amount of shielding that had to be placed around components within the experimental areas. The original H^+/H^- beam split in the switchyard was in the horizontal plane. Today that split is in the vertical plane with the H^+ beam rising to about 7 ft, and then brought back down to 5 ft for continuation along the original Line A. If there is an experimental, activation, or cost reason, the beam elevation entering the FMTS tank can easily be adjusted between 5 ft and 7 ft above the floor. However, the crane hook height is 40 ft above the floor and every foot the beam line is raised reduces the hook clearance a foot. Ref: 117Y-261166 E-1.

The top of the stalk is determined by the height of the stalk. In the discussion above, the distance from the target centerline and the top of the stalk was determined to be 9 ft-3.5 in. Add this to the 5 ft distance from the floor to the beam results in the stalk top being at 14 ft-3.5 in. above the floor [6981 ft-3.5 in. (6981.3 ft)].

The wall thickness of the cylindrical portion of the vacuum tank is determined by codes to be of the order of $^1/_2$ in. The effect of the ports attached to the wall of the tank must be analyzed. The floor and lid can be flat plates on the order of 4 in. thick. Because of the protection provided by the internal shielding, elastomer seals may be used on the tank flanges.

The material of the tank may be stainless steel, carbon steel, or copper-plated carbon steel, determined by cost and activation.

The tank lid will have an opening about 2 ft larger than that required to support the stalk, in order to provide access to the shielding adjacent to the stalk. This provides ease in connecting cooling lines and rearranging the shielding for differing stalk configurations. The tank lid opening is proposed to be 66 inches east-west by 36 inches north-south. The opening is framed by thickening its edges to 8 in. for a width of 4 in. This is accomplished by cutting a 74-in. × 44-in. hole into the 4-inch-thick lid and securely welding in a rectangular frame of 4 in. wide × 8 in. high bars. The top of this frame is machined to accommodate seals, alignment pins, and tie-down bolts.

An option exists to provide four columns between the floor and the lid to support the central portion of the lid to reduce deflection. The atmospheric load on the lid is 152 tons (187 tons at sea level). A stalk could weigh as much as 10 tons. The lid weighs 15 tons (one-half the crane capacity). The columns would form part of the in-tank shielding, but be of precise length and keyed into position.

The lid discussion is for the purpose of showing that a simple flat plate of reasonable thickness and weight is adequate. Other options are available, such as stiffening beams or more columns.

The height of the cylindrical portion of the tank is determined by the vertical location of the stalk (6981 ft-3.5 in.), the thickness of the stalk top flange (2 in.), the thickness of the rectangular washer between the stalk and the lid (4 in.), and the thickness of the lid (4 in. plus 2 in. lip = 6 in.), a total of 12 in. This locates the top flange of the tank at 6980 ft-3.5 in. or 13 ft-3.5 in. above the concrete floor.

The 4-inch-thick rectangular washer has outside dimensions of 74 in. × 44 in. to mate with the reinforced hole in the tank lid, and inside dimensions of 44 in. × 14 in. to accommodate the 42 in. × 12 in. stalk that hangs from a 50 in. × 20 in. flange that is 2 in. thick. This washer provides a convenient location for passage of cooling lines and instrumentation from the internal shielding to the support systems outside the tank, as it is much easier to modify than the tank lid or walls.

Note: The 4-inch-thick rectangular washer provides versatility in stalk/tank design in that it does not have to be flat. The washer may have a flanged box shape that places the stalk-sealing surface above or below the tank lid elevation.

Five flanged ports exist on the cylindrical wall of the tank, three of which are centered at the beam elevation (60 in. above the concrete floor). A 36-inch-diameter port is located on the west side of the tank for beam entrance. The large diameter allows lining the beam entrance duct with annular shielding to protect the port and entrance beam line. An 18-inch-diameter port is located on the north side to provide for any future experiments that may need such access. A rectangular port 48 in. wide × 24 in. high is located on the south side to accommodate horizontal target or sample insertion if it should be desired in the future.* The two remaining ports are 14 inch in diameter, 8 ft apart, and located as close to the floor as possible on the western side of the tank (Fig. 3). These are for vacuum pumping and water drainage. Additional ports may be added as desired.

*Note: Should the experimental program dictate short sample irradiation times, it would be possible to decouple the sample holders from the target system and remove the samples horizontally or vertically. An example of horizontal targeting is at ISIS (http://www.isis.rl.ac.uk).

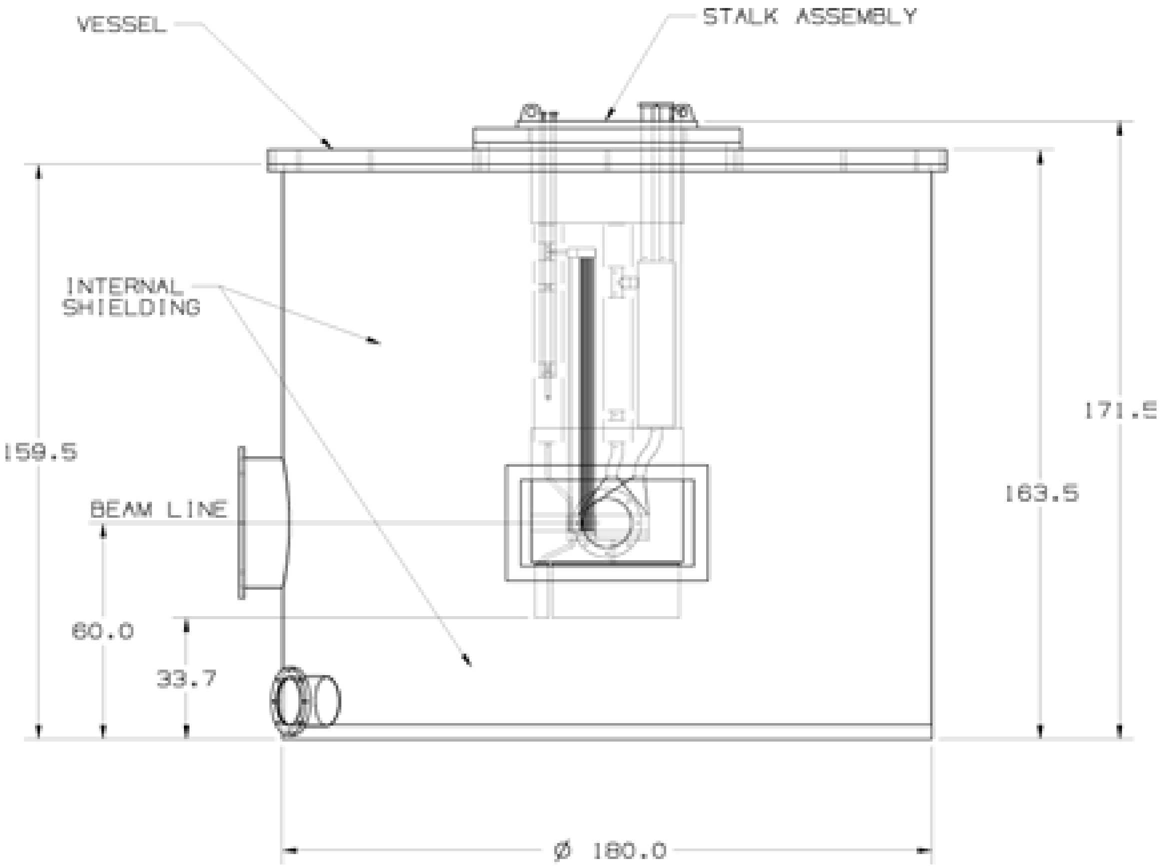


Fig. 3. Vacuum vessel and stalk assembly dimensions.

The removal of water leaked into the tank must be considered. Options include sloping the floor, internal pans and gutters, and sweeping dry gas through the tank internals.

The concrete floor of Area A at the location proposed for the tank needs to be accurately surveyed for flatness and levelness to assure that the top of the tank and the centerline of the beam entrance port are at the proper elevations. It may be prudent to construct the tank an inch or so short and grout beneath it. The thickness of the 4-inch-thick rectangular washer may also be adjusted to correct any elevation errors. The height of the stalks may change after further development; therefore, these dimensions are presented to alert the designer to the interdependency of the component shapes.

Recap: The reference tank is 15 ft diameter, 1/2 in. wall thickness. Lid and floor are 4 in. thick with a reinforced 66 in. × 36 in. rectangular hole in the lid. The tank is 13 ft-3.5 in. high and has 5 side ports. The tank deflections and code analysis were performed by Dave Katonak, ESA-DE, 5-9637.

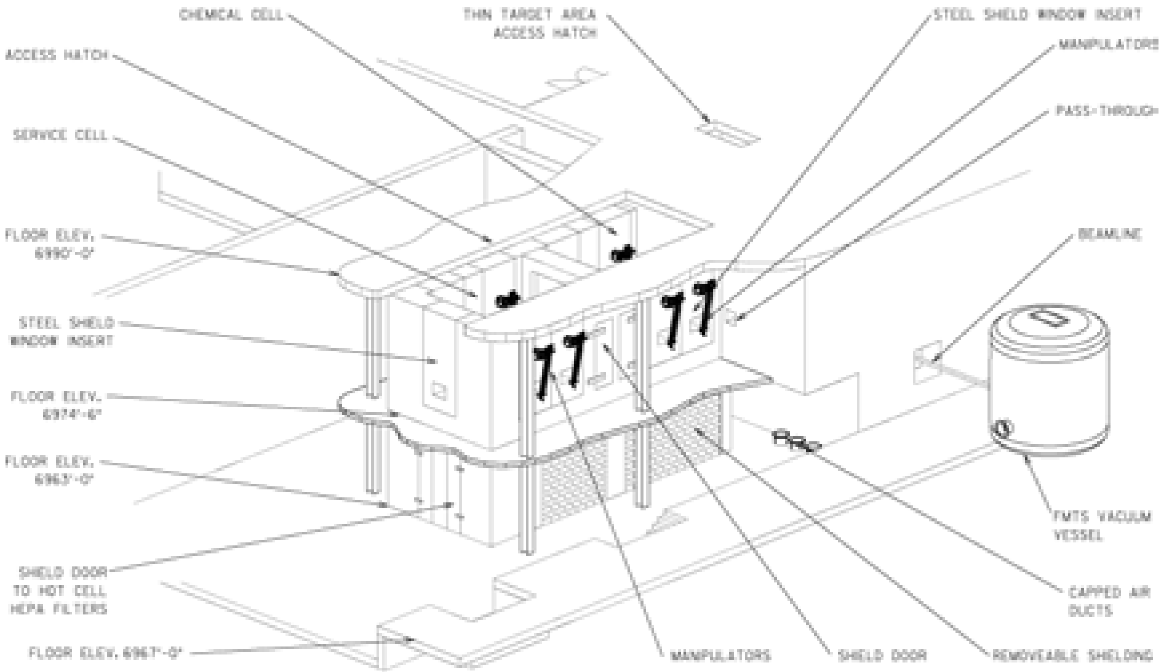
External Shielding

Additional shielding is required around the outside of the tank for personnel protection. The 1970s era criteria for the shielding for the target areas at LANSCE was for 12 ft of steel plus 3 ft of concrete at 90 degrees, and more in the forward direction. The forward direction was not a problem at LANSCE as additional target stations along the beam line provided the shielding. This amount of shielding was adequate, except for some cracks due to the block stacking patterns.

Using the LANSCE shielding for guidance, the mass of material required at the 90 degree direction is 12 ft steel × 490 lb/ft^3 = 5880 lb/ft^2, plus 3 ft concrete × 150 lb/ft^3 = 450 lb/ft^2, for a total of 6330 lb/ft^2.

The FMTS target will be surrounded by at least 4 ft of steel within the tank. As height is important, the shielding over the tank should be 8 ft of steel plus 3 ft of concrete. The top of the stalk flange is at 6981.3 ft MSL. Allow 1.7 ft for utility runs. The 8 ft of steel would extend from 6983 ft to 6991 ft MSL; the top of the concrete would be at 6994 ft. This is 4 ft higher than the top of the hot cells and the historic shielding height along beam line A. For planning purposes, another foot is added, resulting in the top of the shielding being at 6995 ft.

As the crane hook clearance is only 12 ft above the shielding, the top shielding must be arranged to allow easy removal of a 5 ft high × 4 ft wide section to provide a channel through which a stalk may be conveyed on its path to the hot cell (Fig. 4).



FUEL MATERIAL TEST STATION (FMTS) - AREA A ISOMETRIC VIEW

Fig. 4. Isometric view.

The additional shielding required on the north and south sides of the tank can be satisfied by using any combination of from 8 ft of steel plus 3 ft of concrete, to 23 ft of only concrete (2.41 ft of concrete = 1 ft of steel in shielding high-energy particles). Water systems, liquid metal storage tanks, tank internal shielding storage, stalk storage, and alcoves for electrical, instrumentation, and water manifolds will be embedded within the external shielding. It may be desirable to provide a few feet of clearance for personnel access to the sides of the tank, especially the flange areas. Therefore, the volume of shielding must be large enough to accommodate these considerations, favoring the use of concrete over steel.

The support components must be positioned within the shielding for convenient crane coverage. The northwestern portion of this shield mass cannot be reached by a crane hook and items located there require either cantilevered or bridged lifts (Fig. 4).

Note: When uncoupled, the northern crane hook has a southern limit that is 25 ft north of the beam centerline and the southern crane has a northern limit that is 4 ft–6 in. north of the beam centerline (9 ft-9 in. south of the north balcony), i.e., 20 ft gap. When coupled, the hooks can cover the general floor space of Area A, approaching 14 ft off the north and south walls, and 8 ft-8 in. off the east and west walls, but not the hot cell area.

Stalks will be handled by the south crane. Handling in-tank shielding requires both cranes; therefore, storage pits for this shielding must be located at least 8 ft east of the balcony. Water and vacuum systems could use either crane, but if located on the north side, must be at least 8 ft east of the balcony.

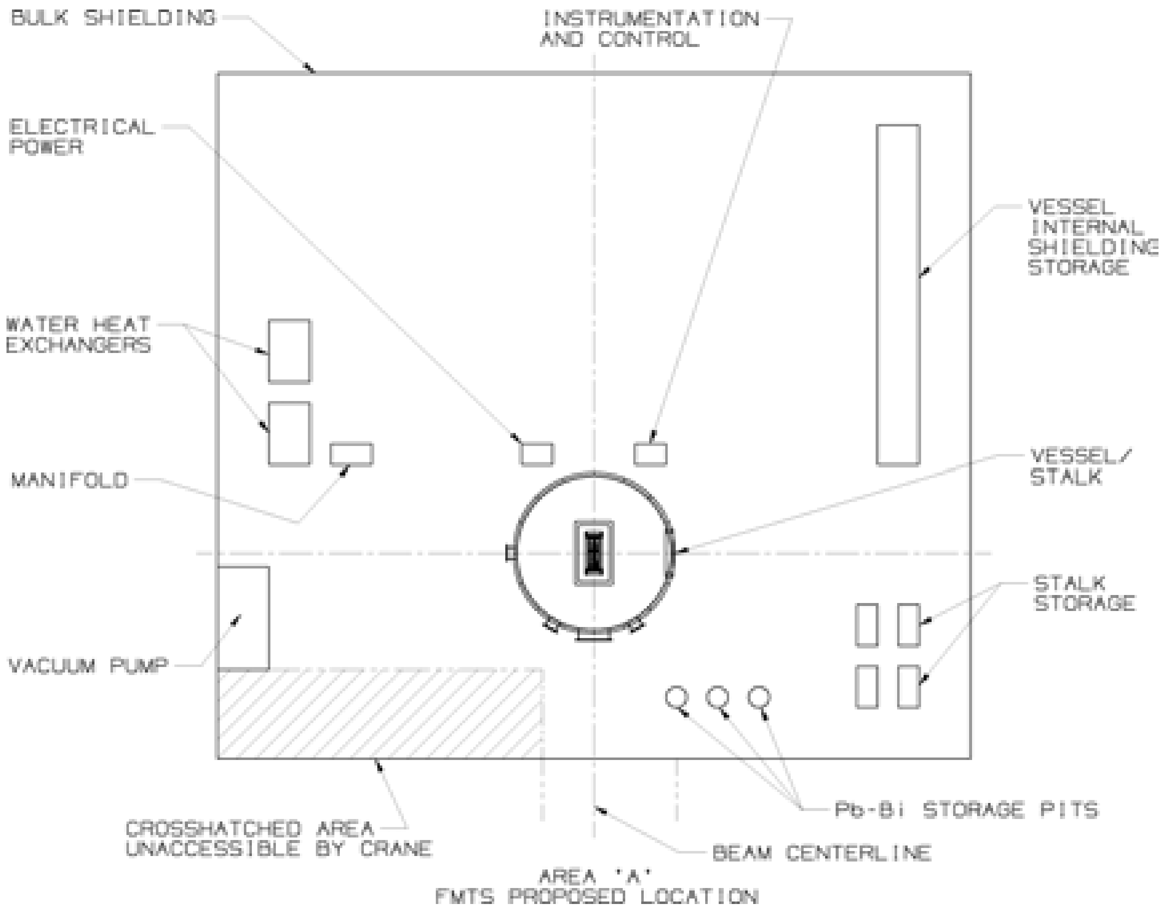


Fig. 5. Conceptual layout of FMTS.

This experience-based approach will provide adequate guidance for the conceptualization of the facility. After much more is known about the internal components and the support systems, a more rigorous shielding design can be undertaken utilizing modern design codes.

Cooling Systems

FMTS must provide cooling compatible with the desires of the experimentalists; water, PbBi, He, or Na. Water, PbBi, and He primary coolant systems could reject their heat to one of the existing XO cooling systems, which, in turn, dump their heat through tower-cooled water systems. A Na primary system might be air-cooled.

The cooling water requirements of the stalks and the internal shielding must be analyzed to determine system parameters. It is intended that the primary cooling systems be located on the stalk and/or within the external shielding near the top of the tank. The components of the secondary systems may be located at any convenient place, perhaps within Area-A, as tower water and XO-1 cooling system water that was used to cool power supplies circulates around the balcony. The XO-1 system provides demineralized water at 110 psi with a return pressure of 19 psi around the Area A balcony and to the power supplies above the switchyard. The heat exchanger and pumps for this system are located in the Area A mechanical room over the restrooms.

The XO-2, -3, and -5 systems could be used as secondary cooling systems, rather than their historic use as primary cooling systems.

Vacuum System

One or two 14-inch-diameter vacuum pumping pipes would be located near the floor of the tank and extend out through the external shielding to vacuum pumping stations located on the floor of Area A. These stations would contain blowers, roughing pumps, and cryopumps of large capacity to rapidly reduce the pressure within the tank to the 10^{-5} or 10^{-6} torr range.

As these pipes are located at the floor, they will have a secondary role in providing a drainage path for the removal of water that might have leaked into the tank.

Electrical Power System

A few tens of kilowatts of electrical power will be available at the top of the tank for the operation of pumps and heaters for sodium and PbBi systems. The breaker panels, transformers, rectifiers, and controllers may be located on the balcony of Area A, where such items are traditionally placed, and the leads may be suspended from the catwalks on the west side of the building to FMTS.

The FMTS electrical power requirements are a fraction of the traditional power delivery to this area.

Instrumentation and Control System

Electronic racks would be located at the balcony level to support the FMTS instrumentation and control systems (I&C). The I&C for facility support systems would conform to LANSCE standards and be permanently installed in these racks. The I&C for the various stalk configurations would be provided with the stalk after off-site testing and temporarily housed in these racks. The stalk I&C

would be LANSCE-compatible so that run-permit, personnel safety, data acquisition, and component control may be operated from the control room or locally. Conduits and ducts will be provided within the external shielding for easy routing of cabling between the racks and the top of the tank and the support systems.

Stalk storage

Irradiated stalks will require shielding for a lengthy period after use. Pits within the external shielding are provided for stalk storage. New stalks ready for use may also be stored in this area as it provides a safe environment for these somewhat delicate assemblies. The I&C, power, and cooling will be available at these pits as required to support stalk storage.

PbBi Storage

It may be desirable to remove the liquid-metal coolants from a stalk before moving the stalk or if the facility is down for an extended time. A few heated tanks provided with the necessary controls, piping, and instrumentation will be located within the external shielding. One or more of these tanks will be connected to the stalk so that the transfer may be remotely performed. One tank may contain PbBi or Na that is only used for checkout of new stalks.

Tank Internal Steel Storage

Some day, the facility will require modification or decommissioning and it will be necessary to remove the internal shielding. A pit is provided in the external shielding to accommodate internal shielding storage.

Hot Cells

The existing two hot cells will be utilized in support of FMTS. A stalk would be remotely transported from FMTS and lowered into the south hot cell for retrieval of the samples. Removal of reusable components, repairs, and modifications could also be performed.

Beam Raster

Any target configuration will require that the LANSCE Line-A proton beam be spread over the face of the target to reduce the power density and optimize the neutron flux in the sample region. A target version presently under consideration consists of two targets, each 3 cm wide, 11 cm high, and 50 cm long, with their vertical centerlines spaced 5 cm apart. This shape is like a Roman numeral 2 (II). The test samples are located between the targets and on both sides.

The proton beam will paint one target during a macropulse, then be deflected to paint the other target during the next macropulse. Therefore, each target is painted for 0.6 milliseconds each 16.7 milliseconds (60 Hz).

Magnets located within the switchyard will tailor the beam for painting the face of the target, and for deflecting the beam to the second target.

Note: Confidence in the rastering technique is required before much effort is expended on detailed target and sample design with the “Roman numeral 2” style of target. The question that must be resolved is whether the components that paint the target faces are located upbeam or downbeam from the components that switch the beam from one target to the other. Andy Jason of LANSCE should be consulted about the nonlinear optic method, and Bob Shafer and Martin Schultz about the rastering method of beam painting.

LANSCE Cleanout and Facility Modifications

A-1 Cleanout

It is proposed to remove all shielding and components within the expected footprint of FMTS within Experimental Area A. Drawings and photographs have been scanned to archival files to document what exists and must be removed. The four files are described below; each contains an index describing the photos or drawings.

Books of photographs from various collections are stored in room 145, MPF-6 (under the stairs, SW corner of building). Applicable photos from the period 1969 to 1984 were scanned and titled with a description that includes negative number, the location, direction facing, elevation of camera, and date taken. These 151 photographs and an index are filed electronically* and are on CDs.

*Ref: Berylene Rogers, 7-0414, <brogers@lanl.gov>

Table 1. Area-A Photograph Descriptions

Photo number example: CN80 3633 indicates a color negative taken in 1980
">" is direction facing, "fxx" camera elevation 69xx or 70xx feet ASL
Area-A floor elevation 6967 feet ASL, beam 6972,
balcony 6990, crane hook & cage ~7007 feet.
The A-1 target box was last replaced in 1984, therefore the earlier photos
do not represent the current in-cell components or canyon shielding.
Use the earlier photos to determine bulk shielding, door, and magnet configurations.

The applicable as-built Area-A construction drawings were scanned to file ACS-HOST:d:\scan_files\Adv_Fuel_Cyc_FMTS\BldgA.

Table 2. LAMPF EXPERIMENTAL AREA-A AS-BUILT CONSTRUCTION DRAWINGS

Giffels and Rosetti Job # 66017, in 1969 and revised to as-built in 8/72
Construction Contract AT(29-2)-1942
Archived as ENG-C 61709 to 61796. Drwg # prefix is LAM-J-
Scanned into file ACS-HOST\c:\scan_files\archive\BldgA

The drawing number logbooks in the possession of Joe Vasquez, LANSCE-7 were searched for applicable drawings.

Sketch drawing numbers begin with SKMP-6-xxxx, and date from 1969 to 1984. The original drawings reside in flat files in room 143, MPF-6. The originals were scanned into file

ACS-HOST:d:\scan_files\Adv_Fuel_Cyc_FMTS\skmp6

Formal drawing numbers begin with 70Y-15xxxxxx, and date from 1971 to 1987. The selected drawings reside on aperture cards in MPF-6 room 245 and were scanned into file

ACS-HOST:d:\scan_files\Adv_Fuel_Cyc_FMTS\MP_Drwgs

This file also contains 117Y-261166, which is a controlled drawing of the component instrumentation in the switchyard.

All drawings and their indexes have been put onto a CD containing 487 files occupying 512 megabytes. Berylene Rogers, 7-0414, brogers@lanl.gov has a copy and will store it electronically.

Utilizing the above drawings and photographs, an estimate was made of the number of items that would require removal.

Table 3. LIFT COUNT FOR AREA A, A-1 TARGET CELL REGION

HOT	COLD	Blocks	Location	
20	30	50	Counterweight base	SKMP6-334
50	272	322	East end, 1' to 9'	SKMP6-421
				70Y-157594-604
65	221	286	West end, 1' to 9'	SKMP6-425
				70Y-157461
70	141	211	EPICS beam line fill	70Y157590
30	70	100	LEP beam line fill	70Y157925
7	65	72	Inside SWYD at Area A face	70Y157608
20	25	45	In Area A at SWYD face	70Y157848
0	15	15	Door AIA	70Y158039&874
			Filled with hundreds of 6x6x12 concrete bricks	
40	60	100	Door AIB	70Y157736&875
20	30	50	Door AIC	70Y157737&876
			~100 concrete brick	
66	0	66	Incell blocks, west end	SKMP6-505
58	0	58	Incell blocks, east end	SKMP6-506
100	0	100	Other incell blocks	
20	0	20	Beamline components	
50	50	100	LEP & EPICS components	
0	100	100	Covering concrete blocks	
20	40	60	Concrete blks within shield mass	
30	150	180	N&S 9 ft to 23 ft steel & concrete	
10	40	50	EPICS stand	
10	80	90	LEP stand	
686	**1389**	**2075**	**TOTAL**	

Working part time during August and September, 2002, LANSCE-7 personnel removed 87 concrete shield blocks weighing approximately 908 tons, and perhaps another 100 tons of casks and equipment stored on top and around the A-1 shield mass. The cost for this effort was $93K.

Cooling Systems

The XO-2, -3, -4, and -5 cooling system piping serving Area-A will be removed from the switchyard and the portion of Area-A that will be stripped of shielding and the existing components. The XO-4 system currently serves the switchyard; therefore, the removed portion must be blanked off.

The XO-2, -3, -4, and -5 systems were designed with 300 psi supply pressure and 60°F temperature rise to remove the heat from the small channels within the conductors of rad-hard magnets and cooling tubes of other components. Their possible new use as secondary systems will require much lower supply pressures and temperature rises. Therefore the water flow rates will be much higher. These systems require analysis to determine what changes will be required in their possible new roles.

Note: The LANSCE water expert is Jeff Casados, LANSCE 2, 7-5631, pager 4-3152.

Hot Cells

The existing two hot cells will be utilized in support of FMTS.* The north cell has historically supported radiochemical research and contains a rabbit system that extends to locations within the various experimental areas. The south hot cell has been utilized in the maintenance and repair of activated components.

The hot cells contain legacy components that must be removed and the cells decontaminated to ease the installation of new equipment.

Some maintenance is required. The oil in the 9 windows should be replaced and the balloon on their reservoirs replaced. The manipulators should be tuned. Not all the positions are fitted with manipulators.**

The area below the south cell contains the HEPA filters through which the exhaust air from Areas A, B, C, A-East, and the switchyard are routed. The demineralizer beds and filters (now abandoned) for the XO water systems are also located in this area. The floor of the south cell consists of steel plates that may be removed for vertical access to the area beneath, providing the ability to remove the HEPA filters and demineralizers remotely. The abandoned components will be removed, making that space available to support the hot cell above.

The north portion of the floor of the south hot cell will be removed and modified to allow a full-length stalk (11 ft-6 in.) to be lowered through the hot cell so that the manipulators may work on any area of the stalk, including the top flange.

The hot cell roofs contain plugged penetrations that allow items to be lowered into the cells without having to roll aside the roofs. Penetrations of this nature are required when utilizing bottom-entry casks for hot item transfer. Some of the existing penetrations will be used for transferring samples out of the hot cells. One or two of these penetrations will be enlarged to permit the passage of a stalk.

*Ref: "Los Alamos Meson Physics Facility Hot Cell Complex, Mahlon T. Wilson, pp. 105-109, Proceedings of the 17th Conference on Remote Systems Technology, 1969, American Nuclear Society."

**Note: Additional manipulators and lead glass windows are in storage in Wing 9 of the CMR Building. These were rescued from the debris of the Maintenance and Disassembly Building of the nuclear rocket program at Jackass Flats, Nevada Test Site, and date from the 1960s. They are from the same source as the manipulators and windows that are at LANSCE. All these manipulators and windows are in reasonably good condition and are available for use. The Wing 9 supervisor is Wayne Taylor, 7-4653, wtaylor@lanl.gov, their manipulator maintenance guru is James Gallegos, jamesg@lanl.gov. The availability of these items makes it possible to consider the construction of additional hot cells as may be desired to enhance the usability of FMTS.

Cranes

The Area A cranes appear to be in good condition. A desirable enhancement would be to provide hooks that can be rotated remotely. If necessary, the south crane trolley and draw works could be replaced with one that provides a higher hook height and has the hook positioned further to the north.

Cost Estimate

Relatively early in the project costs were estimated for the FMTS, and this information is presented below.

Table 4. FACILITY COST ESTIMATE (BASIS)	**$K/wk**		
	6.86	300	Tech $K/yr, w/M&S
	4.57	200	Tech $K/yr, no M&S
	9.14	400	TSM $K/yr, w/M&S
	6.86	300	TSM $K/yr, no M&S

Table 5. A-1 IRRADIATION FACILITY COST ESTIMATE

$K	$K		TIME wks	TSM #	TECH #	COMPONENTS $K	
5167		**FACILITY PREPARATION**					
920	FACILITY REFURBISHMENT						
	120	Water systems: XO-2, XO-6	6	0.5	2	10	
	140	HVAC	6	0.5	2	30	
	120	Electrical	6	0.5	2	10	
	120	Rad air exhaust	6	0.5	2	10	
	255	Area A cranes	10	0.2	2	100	
	165	Monitor (remote handling)	10	0.2	2	10	
	156	Hot cell-manipulators	10	0.1	2	10	
	44	Hot cell-windows	9	0.1	0.5	5	
	69	Hot cell-decon	4	0.1	2	10	
2923	A-1 TARGET CELL CLEAN-OUT						
	174	Clear out egress areas	4	1	5	0	
	87	Set up temporary storage	2	1	5	0	
	178	Transport casks	16	0.5	0.5	50	
	50	Remove Target drive	1	1	6	0	
	50	Remove Porfile Monitor	1	1	6	0	
	46	Reposition Monitor	1	0.5	6	0	
	183	Open cell doors	4	0.5	6	0	
	46	Remove beam pipe to A-2	1	0.5	6	0	
	46	Remove beam pipe from swyd	1	0.5	6	0	
	46	Remove water piping	1	0.5	6	0	
	46	Remove electrical leads	1	0.5	6	0	
	56	Remove 2 in. baseplate	1	0.5	6	10	
	955	Remove 464 hot items	19	1	6	0	
	50	Remove 155 cold items	1	1	6	0	
	100	Crane rental @$1k/day w/crew (aids bldg crane)					'02 Means 01590-600
	377	Transport hot components	10	0.1	5	25	
	250	Disposal charge @ $500 ea					
	184	Install shadow shields	4	1	5	10	

Table 5. A-1 IRRADIATION FACILITY COST ESTIMATE

$K	$K		TIME wks	TSM #	TECH #	COMPONENTS $K	
697	SWITCHYARD PREPARATION						
	302	Clear path to Thin Target Area	6	1	6	0	
	258	Remove interferring components	6	0.2	6	0	
	137	Upgrade XO valve gallery	6	1	2	0	
628	453	Remove 222 hot items	9	1	6	0	
	402	Remove 1234 cold items	8	1	6	0	
	85	Crane rental @$1k/day w/crew					'02 Means 01590-600
	191	Transport hot components	5	0.1	5	15	
	111	Disposal charge @ $500 ea					
	-184	Delete shadow shields					
	-302	Delete path to Thin Target Area					
	-129	Delete 1/2 removal swyd interferring components					
2384		**TARGET STALK**					
941	STALK BODY						
	66	Framework	4	0.5	1	20	
	66	Shielding	4	0.5	1	20	
	144	Heat Exchanger	40	0.1	0.1	80	Keith Woloshun
	184	Pump	40	0.1	0.1	120	Keith Woloshun
	94	Flow Meter	40	0.1	0.1	30	Keith Woloshun
	62	Expansion tank	10	0.2	0.2	30	Keith Woloshun
	62	Dump tank	10	0.2	0.2	30	like exp tank
	56	Piping	10	0.2	0.4	10	
	23	Heaters	8	0.1	0.1	10	
	56	Instrumentation	4	0.5	1	10	
	129	Assemble	4	1	3	10	
900	TARGET & REFLECTOR ASSY						IP800 ✕ 1.2
	0	Target housing					
	0	Sample holders					
	0	Samples					
	0	Assemble					

Table 5. A-1 IRRADIATION FACILITY COST ESTIMATE

$K	**$K**		**TIME wks**	**TSM #**	**TECH #**	**COMPONENTS $K**	
543	STALK ASSEMBLY						
	51	Mount target & reflector	2	1	2	5	
	141	Instrumentation	4	1	2	50	includes profile monitor
	74	Gas systems	4	1	1	10	
	51	Heaters	2	1	2	5	
	47	Insulation	2	0.5	2	10	
	47	Fill w/ PbBi	1	2	2	15	1500 lbs @ $10/lb
	133	Test	4	2	2	5	
7065		**FACILITY INSTALLATION**	**New steel plate $0.45/lb at mill, Means 05120-560**				
1124	VACUUM VESSEL						
	776	Tank 13 ft dia × 15 ft hi, 34 tons	20	0.5	2	410	$6/pound fabricated
	349	Tank Lid 14 ft dia, 3 in. thk, 10 tons	20	0.5	1	120	$6/pound fabricated
2069	INTERNAL SHIELDING						
	1975	Cu plated steel	16	1	3	1500	1M# @ $1.50/lb
	93	Cooling tubing	4	1	2	2	
1302	EXTERNAL SHIELDING		Eval existing matl, substitute conc block for steel				
	939	8-ft-thick steel shell around tank	12	1	4	500	3530 tons/400t new
	196	4-ft-thick concrete around steel shell	4	1	4	50	544 cu yds/100 new
	167	Earthquake bracing^	4	0.5	2	94	Means 17100-410
935	SWITCHYARD & BEAMLINE						
	83	Beam pipes	4	0.5	2	10	
	66	Focus magnets	4	1	1	2	Refurbish existing
	94	Power supplies	4	1	1	30	Upgrade existing
	146	Beam oscillating magnets	6	1	1	50	
	196	BO power supply	6	1	1	100	
	51	Vacuum system	2	1	2	5	Refurbish existing
	141	Diagnostics	4	1	2	50	
	74	Beam blocker	4	1	1	10	Refurbish existing

Table 5. A-1 IRRADIATION FACILITY COST ESTIMATE

$K	$K		TIME wks	TSM #	TECH #	COMPONENTS $K	
578	INSTRUMENTATION & CONTROL						
	271	Control software	20	1	0.5	20	
	210	Interface hardware	10	1	1	50	
	96	Connections	4	1	2	5	
375	COOLING SYSTEM						
	66	XO2 Piping to tank lid area	4	0.5	1	20	600kW to PbBi then XO2
	146	Shield cooling primary sys	4	0.5	1	100	a few kW to XO2
	164	I&C, including valving	4	1	1	100	
207	VACUUM SYSTEM for TANK						
	56	Piping	2	1	2	10	
	86	Pumps	4	0.5	1	40	New & refurbish
	33	Exhaust filtering	2	0.5	1	10	
	33	I&C	2	0.5	1	10	
112	GAS SYSTEM FOR STALK, pressure and purify						
	28	Gas supply piping	2	0.5	1	5	
	42	Valving	2	1	1	10	
	42	I&C	2	1	1	10	
362	STALK BOTTOM ENTRY CASK^						
	216	Cask 62 tons	4	1	2	125	Steel @ $1/lb
	146	Rail mounted gantry crane	4	0.5	1	100	
		^Only needed if cannot move stalk through air or block canyon to hot cell					
14616	**TOTAL CONSTRUCTION COST (TCC)**						
731	CONSTRUCTION MANAGEMENT						
	731	5% of TCC					
2923	ENGINEERING AND DESIGN						
	2923	20% of TCC					
731	PROJECT SUPPORT-PM, PC, QA, Procurement						
	731	5% of TCC					

Table 5. A-1 IRRADIATION FACILITY COST ESTIMATE

$K	**$K**	**TIME wks**	**TSM #**	**TECH #**	**COMPONENTS $K**
19000	**TOTAL ESTIMATED COST (TEC)**				
3800	CONTINGENCY 20% of TEC				
22801	TOTAL ESTIMATED COST WITH CONTINGENCY				
3800	OTHER PROJECT COSTS—ED&D, CD, ES&H, PM for OCP				
	3800 20% of TEC, incl OPC contingency		Incl $500K for safety analysis, docs, permits		
26601	**TOTAL PROJECT COST (TPC)**				
	$26,601K				

At this stage in the project it is apparent that the estimate for the tank is too high and for the switchyard and beamline is too low. This whole estimate requires updating, preferably after completion of the PERT exercise begun by Dave Katonak, ESA-DE, 5-9637.

FMTS Operations

Will be completed later if the project resumes.

PART 2: POWER AND PEAK POWER DENSITIES FOR FOUR TARGET OPTIONS

Author: Gordon Willcutt

Power distributions for the targets, fuel modules, and materials sample tubes were calculated for four target options. Three 50-cm target depth options include:

(a) light-water-cooled clad-tungsten plates with 65% tungsten and 35% water,

(b) a lead bismuth eutectic (LBE) target where the LBE acts as both target and coolant, and

(c) an LBE-cooled clad-uranium-10 wt% moly plate target with 65% plates and 35% LBE.

An additional target used light-water-cooled clad-tungsten rods and rings in which each of ten target tubes included a central tungsten rod and two tungsten rings. The tungsten in the central rod is 0.318 cm in diameter, the flow channels are 0.102 cm thick, and the two tungsten rings are 0.190 cm thick.

Stopping lengths were estimated for the four targets. The ratio of target length to stopping length was 1.49 for the light-water-cooled clad-tungsten plates, 1.14 for the LBE target, and 1.59 for the LBE-cooled clad-U-10Mo plates, so these three targets have more than enough material to stop the beam. For the ten tubes with the tungsten rod/rings, the ratio of target length to stopping length is only 0.56, so if this option were pursued further more tubes would need to be used.

Table 6 shows a power comparison for the four target options. Note that for all four options, the coolant in the materials samples tubes was modeled as LBE in the MCNPX calculations.

Table 6. POWER DISTRIBUTION FOR FOUR TARGET OPTIONS				
Target Material	**Tungsten Plates**	**LBE**	**U-10Mo Plates**	**Tungsten Rods and Rings**
Coolant	Light-water	LBE	LBE	Light-water
Powers by Region	kW	kW	kW	kW
Total in Target	425.8	370.7	581.2	235.8
Center Fuel Region	63.8	25.8	33.9	44.9
Left Fuel Region	72.1	33.3	43.6	54.1
Right Fuel Region	72.2	33.3	43.8	54.1
Materials Samples Tubes	36.9	36.3	36.8	36.6
Total All Regions	670.8	499.4	739.3	425.5
Fractions by Regions				
Target	0.635	0.742	0.786	0.554
Fuel	0.310	0.185	0.164	0.360
Materials Sample Tubes	0.055	0.073	0.050	0.086

Table 7 shows a comparison of peak power densities in the target and fuel regions for the four target options. Note that the highest power densities in the fuel are for the clad-tungsten plates target-cooled by light-water where the fuel is also cooled by light-water.

Table 7. PEAK POWER DENSITIES FOR FOUR TARGET OPTIONS				
Target Material	**Tungsten Plates**	**LBE**	**U-10Mo Plates**	**Tungsten Rods and Rings**
Coolant	Light-water	LBE	LBE	Light-water
Power Densities	W/cm^3	W/cm^3	W/cm^3	W/cm^3
Target Region				
Target Material	2232	1159	2576	2366
Target Coolant	242	1159	1178	225
Target Shell	1394	1063	1066	465
Center Fuel Region				
Fuel	2105	790	1121	1321
Cladding	80	69	69	97
Side Fuel Regions				
Fuel	1494	597	817	1012
Cladding	82	41	42	59

Thermal-Hydraulic Design Calculations for Two Target Options

Thermal-hydraulic design calculations were performed for the water-cooled clad-tungsten plate targets and for the LBE-cooled clad-U-10Mo plate targets. For each design, the beam switches between two sets of targets that are spaced to permit a central fuel region between them and fuel regions on both sides. The beam has a current of 1 mA and energy of 800 MeV. The beam profile on each set of targets is 1.02 cm wide × 7 cm high so the beam current density is 70 μA/cm^2. Horizontal window frames of 0.99 cm and vertical window frames of 2.00 cm are used to give a total target size of 3 cm wide and 11 cm high.

For water-cooled clad-tungsten plate targets, plate thickness was calculated as a function of position in the beam. Each plate is clad with 0.0127 cm (0.005 in.) thick 316L stainless steel. The peak power density of 2232 W/cm^3 occurs 1 cm into the targets. As the beam penetrates further into the targets, the power deposition decreases with distance into the target. The exit pressure is assumed to be 1.114 MPa (161.5 psia) so the saturation temperature at the exit is 184.6°C. Calculations were performed with 0.102 cm (0.040 in.) coolant channels with a maximum velocity of 5 m/s and an inlet temperature of 20°C. Plate thickness was calculated at 5 cm increments into the targets to give peak surface temperatures that are 40°C below the exit saturation temperature. Table 8 shows the results with thickness varying from 0.25 cm at the peak power density location to 4.71 cm at a depth of 26 cm into the target. Calculations were also performed for 0.153 cm (0.060 in.) channels, but these resulted in lower tungsten volume fractions at each position.

Table 8. PLATE THICKNESSES AND TUNGSTEN VOLUME FRACTIONS VS. POSITION IN TARGET

Position in Target (cm)	1	6	11	16	21	26
Fraction of Peak Power Density	1.000	0.729	0.390	0.192	0.102	0.057
Power Density (W/cm^3)	2232	1627	870	429	228	127
Plate Thickness (cm)	0.25	0.35	0.67	1.38	2.62	4.71
Peak Plate Temp (°C)	180	185	201	237	299	403
Tungsten Volume Fraction	0.665	0.735	0.841	0.916	0.954	0.974

For LBE-cooled clad-U-10Mo targets, plate thickness was also calculated as a function of position in the beam. Each plate is clad with 0.0127 cm (0.005 in.) thick HT-9. The peak power density of 2576 W/cm^3 occurs 1 cm into the targets. As the beam penetrates further into the targets, the power deposition decreases with distance into the target. Calculations were performed with 0.102 cm (0.040 in.) coolant channels with a maximum velocity of 2 m/s and an inlet temperature of 300°C. Plate thickness was calculated at 5 cm increments into the targets to give peak plate temperatures of 1000°C and peak surface temperatures that were less than the 550°C upper limit needed for oxygen control. Table 9 shows the results with thickness varying from 0.60 cm at the peak power density location to 3.21 cm at a depth of 26 cm into the target. Calculations were also performed for 0.153 cm (0.060 in.) channels, but these resulted in lower U-10Mo volume fractions at each position.

Table 9. PLATE THICKNESSES AND U-10Mo VOLUME FRACTIONS VS. POSITION IN TARGET

Position in Target (cm)	1	6	11	16	21	26
Fraction of Peak Power Density	1.000	0.713	0.356	0.172	0.080	0.051
Power Density (W/cm^3)	2576	1837	917	443	206	131
Plate Thickness (cm)	0.60	0.74	1.11	1.67	2.53	3.21
Peak Clad Surf Temp (°C)	540	510	457	414	380	365
Tungsten Volume Fraction	0.825	0.853	0.897	0.929	0.952	0.962

Thermal-Hydraulic Design Calculations for Two Fuel-Cooling Options

Calculations were performed for the highest power rod of the 14 rods in the central fuel module located between the two sets of targets. Cases were performed with either LBE or light-water used to cool the targets and fuel. The fuel diameter is 0.483 cm (0.190 in.), and the clad inner and outer diameters are 0.508 and 0.584 cm (0.200 in. and 0.230 in.), respectively. There is a sodium layer between the fuel and the clad. The rods are in a channel with 0.142 cm (0.056 in.) spacing between the rods and between the rods and the walls of the channel. There is a 12 cm height of fuel in each rod. Note that the peak power densities in the fuel are different for the LBE-cooled targets (1121 W/cm^3) than for the water-cooled targets (2105 W/cm^3). For the LBE-cooled design, the inlet temperature is 300°C, and there is a 2 m/s velocity limit. The peak clad surface temperature is 365°C, well below the 550°C limit for oxygen control. The peak fuel temperature is 452°C. For the water-cooled design, the inlet temperature is 23°C. The peak velocity was set to 4.75 m/s to achieve a 40°C minimum subcooling on the clad surface at the exit for the exit pressure of 0.689 MPa (111 psia). The peak clad surface temperature is 129°C, and the peak fuel temperature is 324°C. Higher peak fuel temperatures could be obtained by using an additional tube outside the clad with a gas gap between the tube and the clad. Table 10 compares results for the LBE-cooled fuel (target was LBE-cooled clad-U-10Mo) and the water-cooled fuel (target was water-cooled clad-tungsten).

Table 10. COMPARISON OF RESULTS FOR LBE AND WATER-COOLED FUEL*		
Coolant	**LBE**	**Light-Water**
Total Power in Central Fuel Region (kW)	33.9	63.8
Coolant Inlet Temperature (°C)	300	23
Coolant Velocity (m/s)	2.00	4.75
Mass Flow Rate in Central Region (kg/s)	10.40	2.39
Coolant Exit Temp (°C)	322.2	29.4
Reynolds Number	53300	25600
Heat Transfer Coefficient (W/m^2-°C)	26800	21400
Peak Fuel Power Density (W/cm^3)	1121	2105
Peak Clad Power Density (W/cm^3)	5.6	7.2
Peak Clad Surface Temperature (°C)	364.7	128.8
Peak Clad Temperature (°C)	387.2	179.2
Peak Fuel Temperature (°C)	452.3	324.2

*Note LBE-cooled fuel used with LBE-cooled clad-U-10Mo target, and water-cooled fuel used with water-cooled clad-tungsten target

PART 3: NEUTRONICS

Authors: Eric Pitcher and Karen Corzine

The neutronics goals of the FMTS are to achieve 1×10^{15} n/cm^2/s peak neutron flux in the irradiation volume, and an average flux of 7×10^{14} n/cm^2/s within a 100-cm^3 irradiation volume. The irradiation zones should provide differing ratios of proton-to-neutron fluxes to allow for testing in mixed spectrum environments. These performance goals are to be achieved with 1 mA of 800-MeV protons.

The goal of 1×10^{15} n·cm^{-2}·s^{-1} peak neutron flux is attained by implementing a split uranium target configuration. The concept of splitting the spallation target to create a “flux trap” between the two segments is not new, nor is the use of uranium as a spallation target material. The Manuel Lujan Jr. Neutron Scattering Center at Los Alamos National Laboratory has used a split tungsten target since its inception in 1985. Both the Intense Pulsed Neutron Source (IPNS) at Argonne National Laboratory and the ISIS Facility at the Rutherford Appleton Laboratory have used uranium targets; uranium was also the primary candidate target material for the German SNQ project in the 1980s. Spallation in uranium produces more neutrons per proton than sub-actinide targets (e.g., tungsten and lead) because of the higher fission cross section of uranium in the 1- to 20-MeV region. Pure, gamma-phase uranium suffers from swelling under proton irradiation, and experience has shown it is viable only at low-current facilities such as IPNS, where the beam current is 5 μA. At higher currents, uranium alloyed with 10 wt% molybdenum (U-10Mo) may perform better, based on extensive reactor-based irradiation data. U-10Mo enriched in U-235 has been irradiated to very high burn-up in reactors, exhibiting good stability. However, there is no experience base for the performance of U-10Mo in a spallation environment.

The pulsed nature of the H^+ beam delivered to Area A (beam on for roughly 1 ms followed by approximately 7 ms beam off) allows the beam to be alternately delivered to one of two positions on the split target. The repositioning of the beam can be accomplished by switching the polarity of the current in a dipole magnet during the 7 ms the beam is off. While the beam is on, the current in this dipole magnet would remain constant. This operating scenario is not difficult to achieve, and is well within the capability of existing magnet technology. Alternating the beam spot position between two points on the split target produces a greater and more uniform neutron flux in the fuel irradiation region located between the target sections.

Figure 6 shows the basic layout of the proposed spallation target system. The footprint of the proton beam is divided into two rectangles, one on either side of the central fuel irradiation region. Additional irradiation volume can be accommodated by placing tubes on the outside of the beam footprints, where the flux is slightly lower than in the central irradiation region.

Three separate targets are to be irradiated. The first target to be irradiated is light-water-cooled tungsten plates, a proven technology in spallation environments. Once testing of this system is complete, LBE will be used to act as both the target and cooling. Afterwards, U-10Mo plates will be added as the spallation target, while LBE will be the coolant.

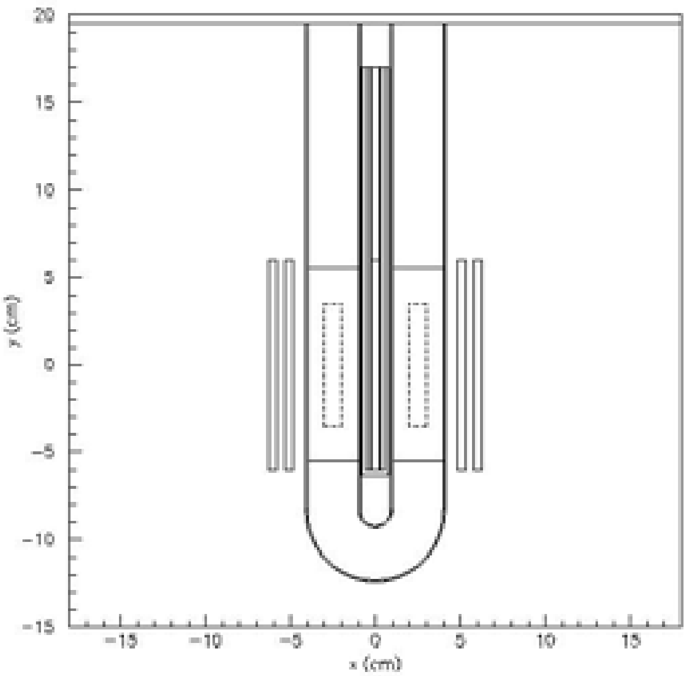


Fig. 6. Elevation view of target and fuel region.
Dotted lines indicate beam spot footprint.

Target Optimization Studies

Variations in the geometry, coolant and reflector materials, and volume fraction of target material can greatly impact neutronics of the test fuel. Studies were performed on each target material to optimize the impact on the fuel.

Tungsten

Tungsten targets are proven technology in accelerator environments and are proposed to go online first in the Area A FMTS. However, tungsten does not perform as well as uranium and must be neutronically optimized to achieve similar fluxes in the fuel region. Different types of coolant and reflector material were studied, along with changes in target geometry and volume fraction.

The baseline tungsten target design had 65 volume percent tungsten plates and 35 volume percent light-water coolant, evenly distributed throughout the 50-cm-long target region. Light-water was also used for cooling the test fuels region. Table 11 shows variations from this baseline case.

Changing the coolant from light-water to heavy-water would increase the total flux by 14% and 16% in the center and side fuel. However, heavy-water cooling is a more expensive system to operate. Since tungsten targets may be irradiated for only a short time, it would be more cost effective to use light-water.

The upstream materials tubes and change in reflector material do not contribute to a significant change in the flux. Nickel is considerably less expensive than tungsten and just as effective as a reflector.

A performance study of 20 tungsten cylindrical assemblies available from the Accelerator Production of Tritium (APT) project showed that this particular rod geometry decreased the flux by as much as 40%. The amount of tungsten in the proton beam is too small to achieve reasonable flux values in the fuel regions.

Thermal hydraulic studies by Gordon Willcutt allowed an increase in target volume fraction from 65% to 80%. This increases the peak and total fluxes by as much as 18%.

Table 11. CHANGE IN THE PEAK AND TOTAL FLUX ($n/cm^2/s/mA$) IN THE CENTER AND SIDE FUEL FOR TUNGSTEN TARGET SYSTEM VARIATIONS

Target/coolant geometry	Target/coolant volume fraction	Reflector	Upstream Materials Tubes	Peak Flux		Total Flux	
				Central Fuel	Side Fuel	Central Fuel	Side Fuel
W/H_2O-plate	65/35	W+15%LBE	Yes	7.2×10^{14}	5.1×10^{14}	5.2×10^{14}	3.7×10^{14}
W/D_2O-plate	65/35	W+15%LBE	Yes	+ 8%	+16%	+14%	+16%
W/H_2O-plate	65/35	W+15%LBE	No	+ 7%	+ 6%	+ 6%	+ 6%
W/H_2O-plate	65/35	Ni	Yes	– 3%	– 2%	– 4%	– 3%
W/H_2O-rod	56/44	W+15%LBE	Yes	– 40%	–31%	–35%	– 27%
W/H_2O-plate	80/20	W+15%LBE	Yes	+18%	+18%	+17%	+14%

LBE

Since LBE is a liquid target operating at >300°C, it acts as both a target and coolant within the target region. Therefore, no optimization studies for change in coolant, geometry, or volume fraction were performed. Table 12 summarizes the fluxes in the center and side fuel regions for an LBE system.

Table 12. PEAK AND TOTAL NEUTRON FLUXES (n/cm2/s/mA) FOR CENTER AND SIDE FUEL FOR AN LBE TARGET SYSTEM

Target/Coolant Geometry	Reflector	Upstream Materials Tubes	Peak Flux		Total Flux	
			Central Fuel	Side Fuel	Central Fuel	Side Fuel
LBE	W+15%LBE	Yes	6.4×10^{14}	5.2×10^{14}	5.1×10^{14}	4.0×10^{14}

U-10Mo

Since a U-10Mo target is ultimately what will yield a flux of 10^{15} n/cm^2/s/mA, the optimization for this target material is essential. Changes in coolant, volume fraction, and placement of upstream materials tubes were investigated for changes in flux.

The baseline U-10Mo target system, like the tungsten target design, had 65 vol% U-10Mo plates and 35 vol% LBE coolant, evenly distributed throughout the 50-cm-long target region. Liquid lead-bismuth eutectic was also used for cooling the test fuels region. Table 13 shows variations from this baseline case.

Changing the coolant from LBE to light-water and heavy-water decreases the neutron flux in the fuel by as much as 20%. Light-water has slightly worse performance than heavy-water because the stronger moderating power of light-water leads to higher parasitic neutron absorption in the U-10Mo.

Deleting upstream materials tubes and increasing the target volume fraction both increase the peak flux in the center fuel region by 10% and 5% in the side fuel. The increase in flux by deleting the upstream materials tubes is comparable to that in the tungsten target system. When the tungsten target volume fraction is increased, the flux increases by 18%. However, the increase in U-10Mo target volume fraction caused the flux to increase by only 5% to 10%. This smaller increase is because the coolant being displaced by increased target volume fraction in the case of U-10Mo is LBE, whereas for the tungsten target the displaced coolant is light-water.

Table 13. CHANGE IN THE PEAK AND TOTAL FLUX ($n/cm^2/s/mA$) IN THE CENTER AND SIDE FUEL FOR U-10MO TARGET SYSTEM VARIATIONS							
Target/coolant geometry	**Target/coolant volume fraction**	**Reflector**	**Upstream Materials Tubes**	**Peak Flux**		**Total Flux**	
				Central Fuel	**Side Fuel**	**Central Fuel**	**Side Fuel**
U/LBE-plate	65/35	W+15%LBE	Yes	1.0×10^{15}	7.5×10^{14}	7.6×10^{14}	5.6×10^{14}
U/D_2O-plate	65/35	W+15%LBE	Yes	–12%	–11%	–12%	–11%
U/H_2O-plate	65/35	W+15%LBE	Yes	–14%	–15%	–17%	–20%
U/LBE-plate	65/35	W+15%LBE	No	+10%	+ 5%	+ 5%	+ 5%
U/LBE-plate	80/20	W+15%LBE	Yes	+10%	+ 5%	+ 7%	+ 7%

Comparison to ATR Fast Neutron Flux Booster

There exists a proposal ("A Fast Neutron Flux Booster Test-Facility in the ATR for Advanced Nuclear Fuel and Material Testing," author unknown, date unknown, unpublished document) to create a Fast Neutron Flux Booster (FNFB) by inserting an active fuel-type filter in a flux trap position of the Advanced Test Reactor (ATR), as a means of hardening the ATR thermal spectrum. A comparison of the neutron flux spectrum obtained with the proposed FNFB in the ATR with that produced in the proposed FMTS is shown in Fig. 7. Also shown in this figure is a typical Advanced Liquid Metal Reactor (ALMR) fast reactor spectrum, which may be considered a reference spectrum that one would want to achieve in an irradiation facility for testing Tier 2 fuels. Below 10 MeV, the FMTS spectrum is clearly better at matching the ALMR spectrum as compared to the FNFB spectrum, which exhibits a significant thermal component. However, the FMTS has a high-energy tail characteristic of a spallation source environment, which does not appear in the ALMR or FNFB spectra.

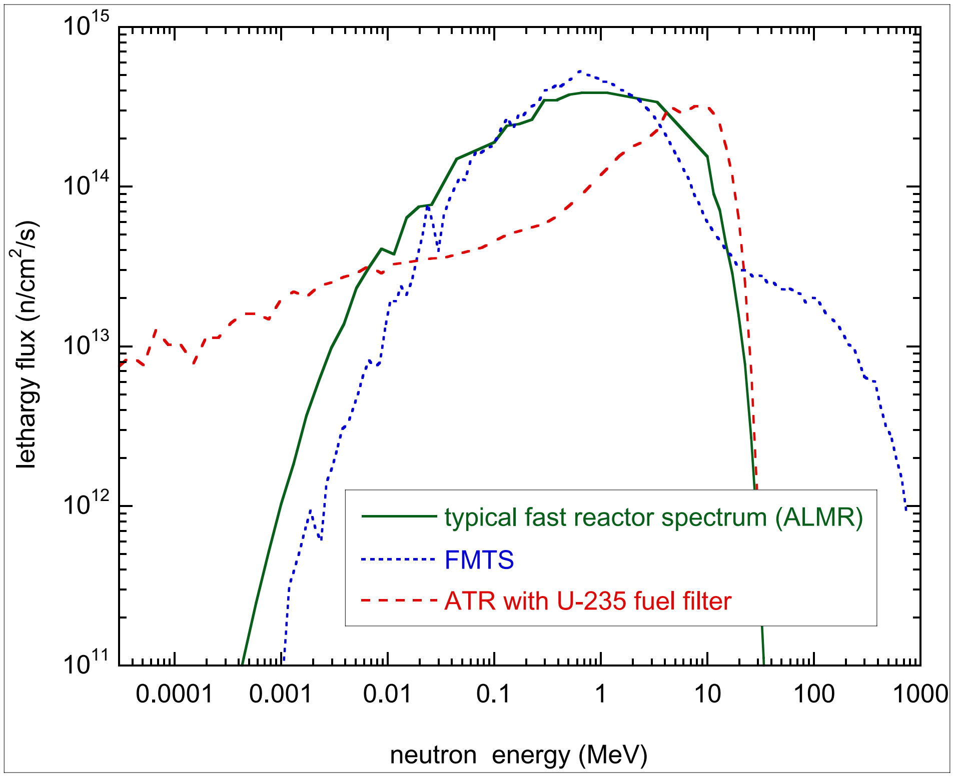


Fig. 7. FMTS and FNFB spectra compared to a typical ALMR spectrum.

Summary

Peak neutronic performance is achieved with an LBE-cooled U-10Mo target. The goal of 1×10^{15} $n\cdot cm^{-2}\cdot s^{-1}$ peak neutron flux at 1 mA beam current is achieved in this system. The total flux, averaged over the 31-cm^3 volume of the central fuel zone, is 7.6×10^{14} $n\cdot cm^{-2}\cdot s^{-1}$. For the side fuel zone, the total flux is 5.6×10^{14} $n\cdot cm^{-2}\cdot s^{-1}$ averaged over 123 cm^3. Damage rates and fluxes are summarized in Table 14 for the center fuel, target window, and upstream materials samples.

Figure 8 shows the spatial distribution of the proton flux in the LBE-cooled U-10Mo target. The beam is well confined within the target. Figure 9 shows the spatial distribution of the neutron flux in a horizontal cut at the target mid-plane. It shows the central fuel tubes are well positioned in the peak neutron flux region, and lower flux in the side fuel tubes. In addition, one can observe the large volume of significant neutron flux in the downstream end of the target that can be utilized for additional fuels irradiation or other applications. Figure 10 shows the spatial distribution of the neutron flux in a vertical slice through the target. Note the relatively flat gradient of the flux in the central fuel zone in this dimension.

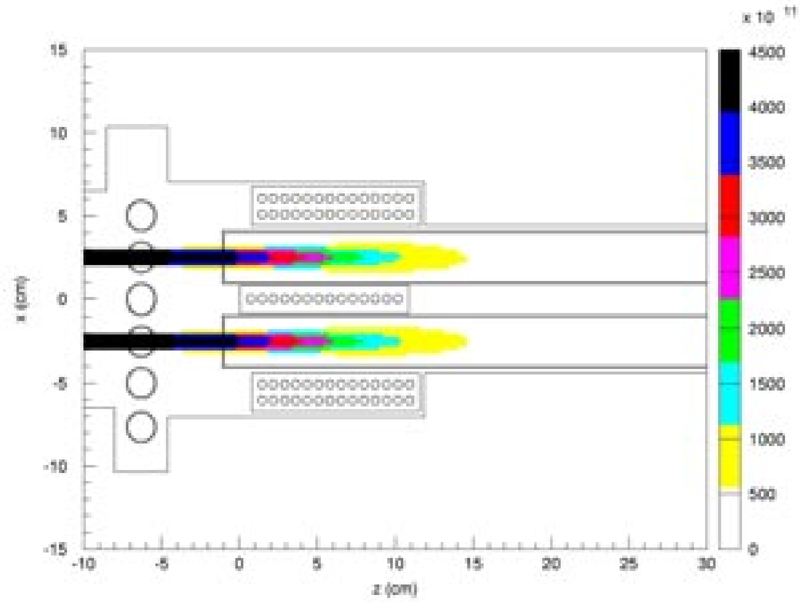


Fig. 8. Proton flux map (p/cm^2/s/mA).

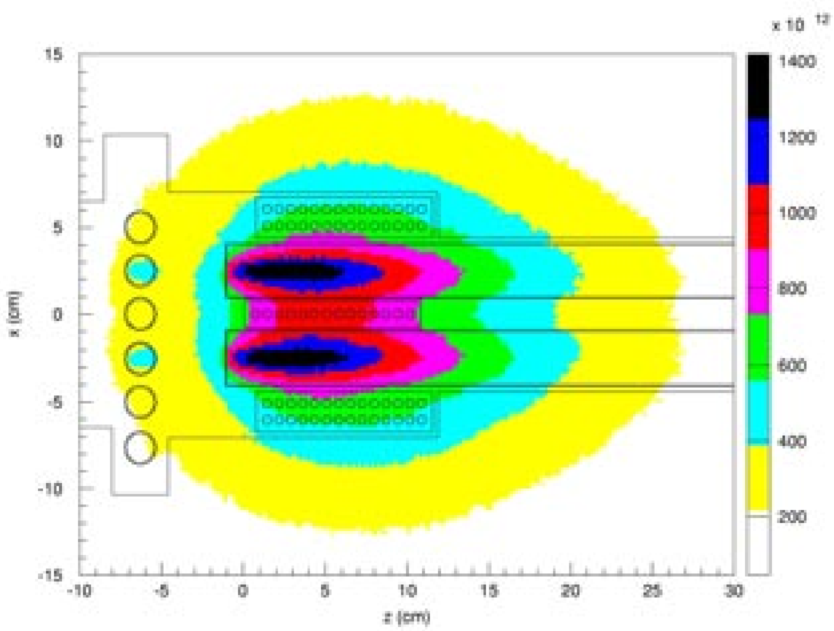


Fig. 9. Fast neutron (E>0.1MeV) flux map (n/cm^2/s/mA).

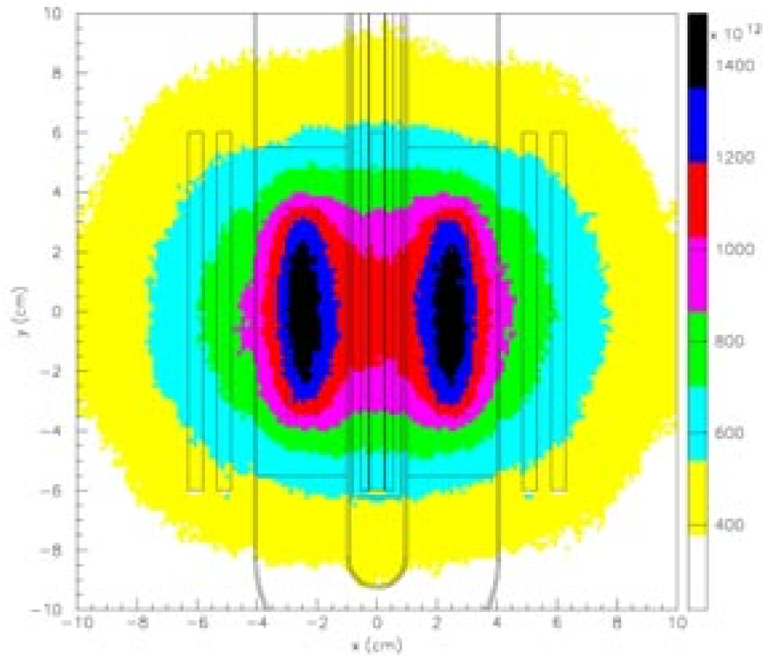


Fig. 10. Neutron flux map (n/cm^2/s/mA) at z=3.5 to 5.5 cm.

Table 14. FLUXES AND DAMAGE RATES FOR A U-LBE TARGET SYSTEM*						
Position	**Peak Neutron Flux (n/cm^2/s/mA)**	**Total High-E (>20 MeV) Neutron Flux (n/cm^2/s/mA)**	**Total Proton Flux (p/cm^2/s/mA)**	**Peak He Prodution Rate (appm/y/mA)**	**Peak Atomic Displacement Rate (dpa/y/mA)**	**He/dpa Ratio (appm/dpa)**
Center fuel zone						
– upstream pin	7.70×10^{14}	2.26×10^{13}	3.79×10^{12}	2.49	6.06	0.41
– peak flux pin	1.00×10^{15}	2.77×10^{13}	4.84×10^{12}	3.71	7.34	0.51
Target window	8.20×10^{14}	3.04×10^{13}	4.30×10^{14}	591.85	43.61	13.57
In-beam materials sample position	4.48×10^{14}	1.36×10^{13}	4.60×10^{14}	514.50	30.22	16.99

*Statistical errors are less than 5%.

PART 4: FMTS FINAL REPORT – ANALYSIS

Author: David Katonak

Vacuum Vessel Analysis

I began working on the FMTS project in early August, filling in after Ray Guffee's departure. I continued by chairing the meetings and doing some preliminary analysis work.

I started working on the vacuum vessel. According to the LANL LIR 402-1200-01-0, this vessel should be designed in accordance with the ASME Boiler & Pressure Vessel code. Based on the code, I determined that a flat head design of 16-foot diameter requires a minimum thickness of 3.8 in. using Type 304 stainless steel. I rounded the thickness up to a more nominal 4 in. thickness value, which was used on all subsequent conceptual and analytical work. The calculations were compared with a DesignStar finite element model that yielded stress concentrations well below the yield for stainless. The head was loaded with the 36,000-pound stalk and an internal vacuum. The restraint was the outer rim of the head, as if resting on the tank. The first analysis, Fig. 11, shows the locations of the stress concentrations.

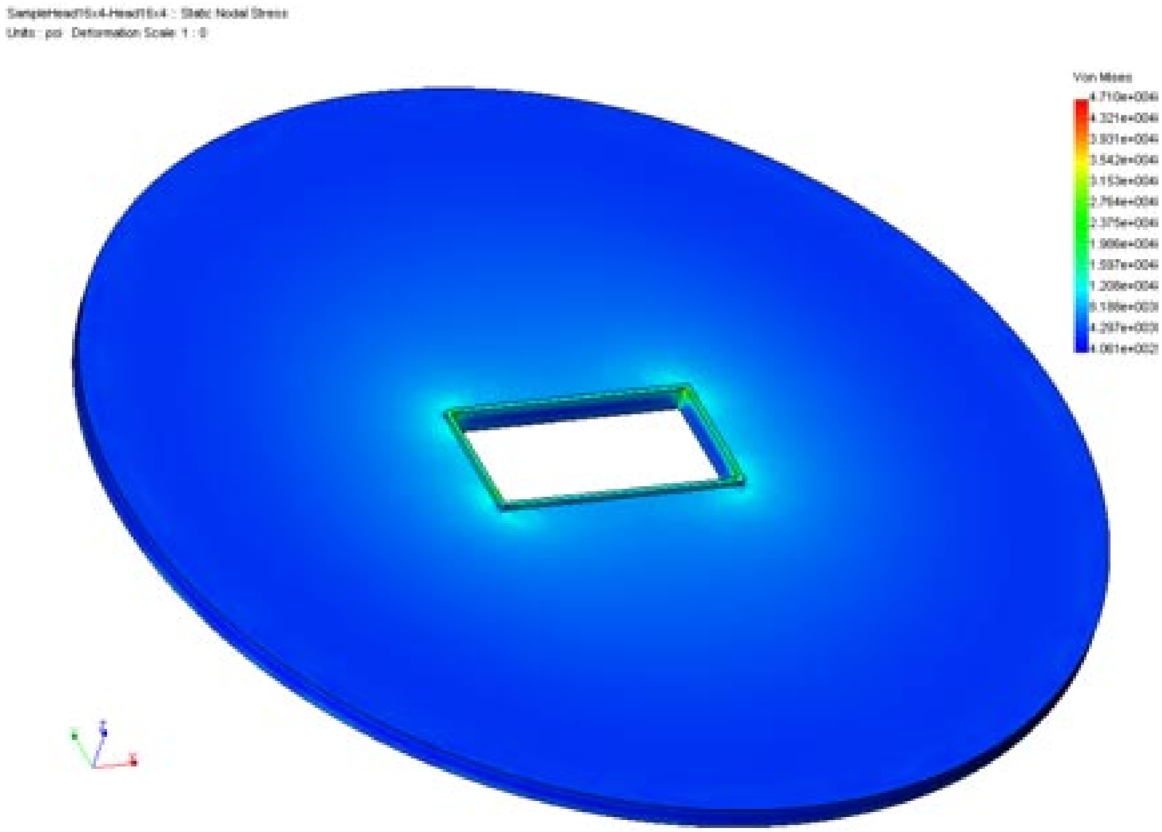


Fig. 11.

This head concept along with the window in the head for the stalk was reiterated and analyzed several times to minimize stress concentrations. The stiffener around the stalk window was increased in size, and a second one was added to the opposite side of the head. This helped reduce the deflection and the peak stresses to a degree. The peak stresses in the structure were found to be in the corners of the stalk window. Increasing the radii and stiffening the window frame greatly reduced the stress concentrations, with the most current analysis shown in Fig. 12.

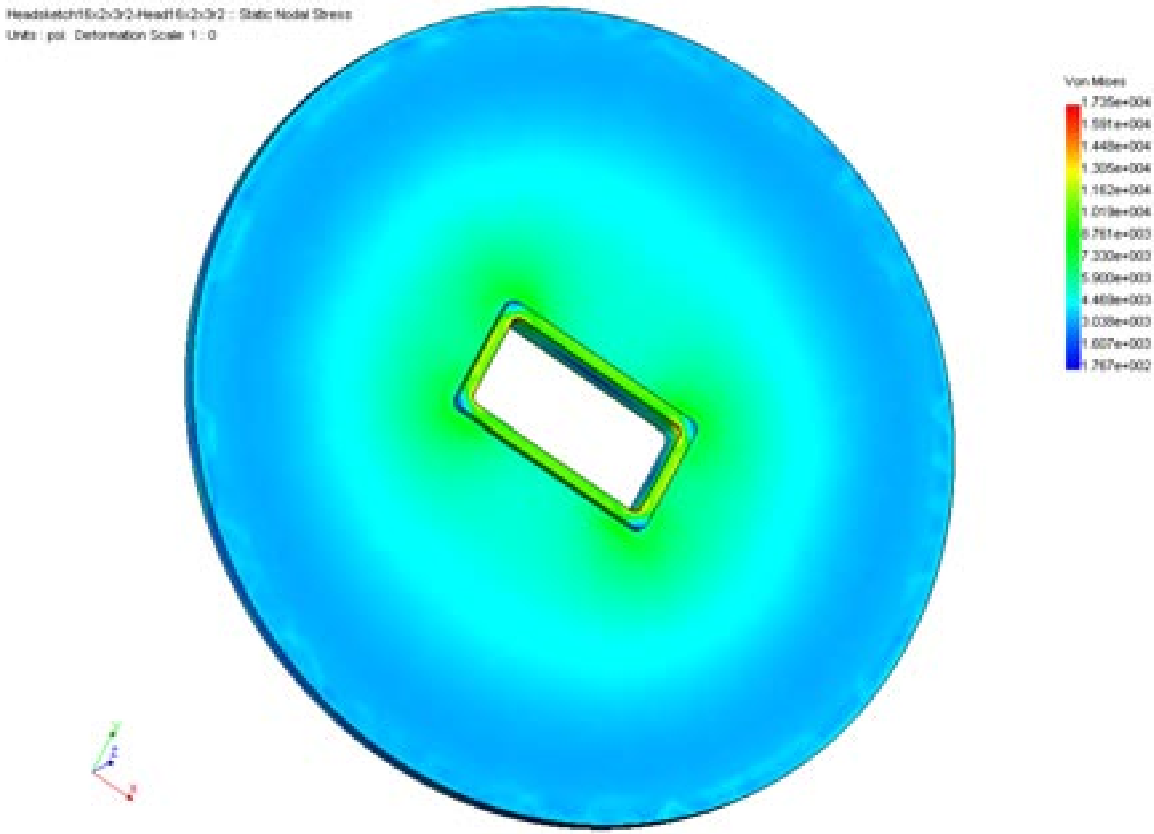


Fig. 12.

Another concept, which reduced the stress concentration, utilizes supports under the head. Supports would be mounted on or near the window frame to absorb the load applied by the hanging stalk. This analysis was also performed. The current design is sufficiently robust to allow the stalk, with an estimated weight of 36,000 pounds, to be hung from the head with or without supports. Figure 13 shows the analysis utilizing stalk supports.

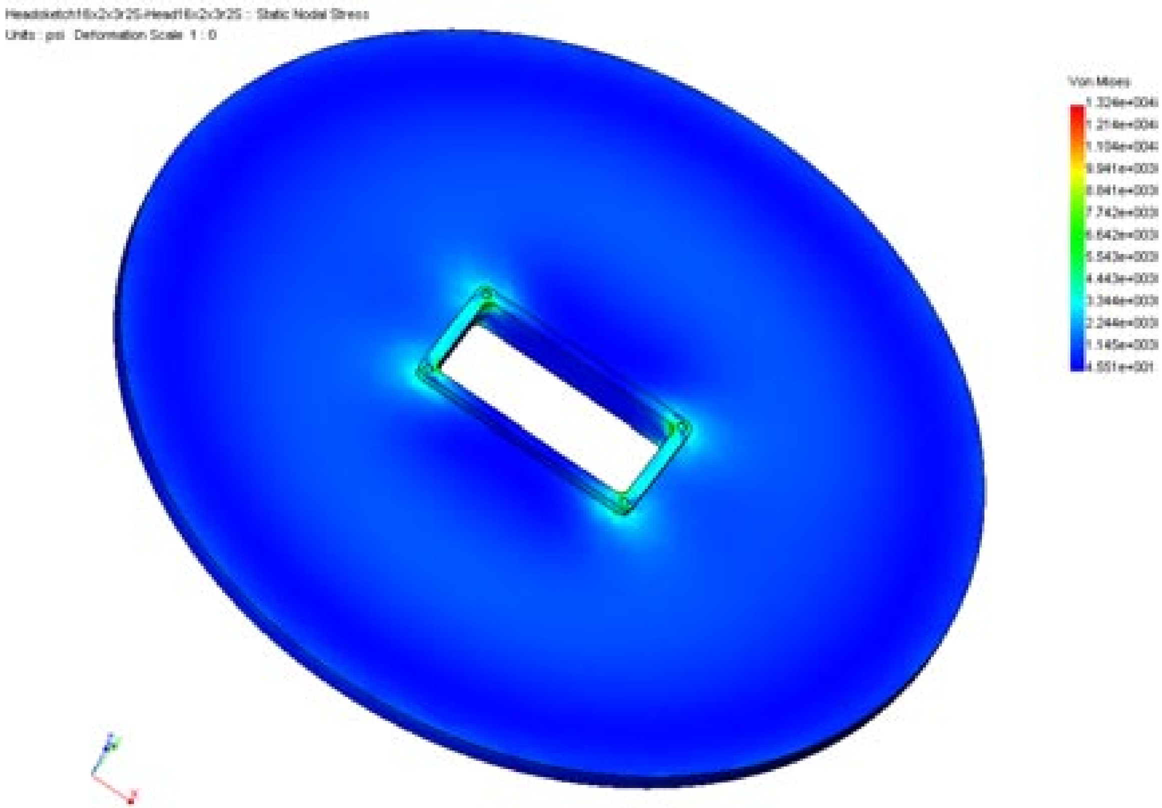


Fig. 13.

Considering the vessel itself, a review of the vessel wall thickness, based on the ASME Boiler and Pressure Vessel Code allowed for a thinner wall thickness. Originally a $^{3}/_{4}$ in. wall thickness was designed. Using this value, we determined that the vessel could handle a pressure differential of approximately 35 psi. A further review, utilizing a wall thickness of $^{5}/_{8}$ in. has shown the vessel concept to handle 19 psi, sufficient for our needs. A $^{5}/_{8}$-inch-thick wall of Type 304 stainless steel would be the recommended approach, unless material of this thickness is difficult to obtain, $^{3}/_{4}$ in. would be the alternative. Concepts have been generated for the required penetrations in the vessel. However, no analytical work was performed; additional work should include analysis of the penetrations in the vessel.

Management

Mahlon Wilson and I started entering project task loading into a PERT chart to help us better define the required tasks for FY03. While we did identify the required tasks, we did not complete the personnel assignments. Task loading is included in Appendix B.

We also reviewed the budget for FY03. We assessed the manpower required, based on the three-year schedule and determined that the FY03 budget should include funding for 15 FTEs, requiring approximately $5 million.

Appendix A to Part 4

Vacuum vessel wall thickness calculations, using the 2001 ASME Boiler and Pressure Vessel Code.

D_0 = outside diameter of the vessel in inches

L = total length of vessel excluding heads in inches

t = minimum required thickness of shell or wall in inches

P_a = maximum allowable working pressure

$L := 153.5 \qquad D_o := 180 \qquad t := .75$

$\frac{L}{D_o} = 0.853 \qquad \frac{D_o}{t} = 240$

From Section II Part D, Subpart 3

Factor $A := .00045$ Factor $B := 6250$

$$P_a := \frac{4 \cdot B}{3 \cdot \left(\frac{D_o}{t}\right)} \qquad P_a = 35 \text{ psi}$$

Alternatively, the wall thickness may be reduced to conserve weight, yet still meeting ASME Boiler & Pressure Vessel Code, and reducing. A thickness of $^5/_8$ in. was explored.

Try a thickness of:

$t := .625 \qquad \frac{D_o}{t} = 288$

From Section II Part D, Subpart 3

Factor $A := .0003$ Factor $B := 4250$

$$P_a := \frac{4 \cdot B}{3 \cdot \left(\frac{D_o}{t}\right)} \qquad P_a = 19.676$$

Appendix B to Part 4

Identify Customers
Customer 1 Chidester
Customer 2 Maloy
Customer 3 Ning Li
Sample req's
Neutronics Target Geom
Heat Removal
dpA Limit/Matl
Run Cycle Fluence
Sample Physics Matl Cooling
Stalk Set Concept
Stalk Set #1
Most Complex Target Config
Stalk Limits Tgt Shield
In Tank Shielding
Tank Dim's
Tank Design
Tank Spec's
Tank Procurement
Tank Fabrication
Tank Inspection
Tank Delivery
Tank Installation
A-1 Ready for Tank
ON (Off Normal) Events ID
ON Mitigation
Facility Ready for Beam
Estab Monitoring Plan
Switchyard Access
Remove Vac Spool
Insert Rad Probe
Procure Long Flex Probe
A-1 Activation Determination
Estab Activation w/in A-1
Generate A-1 Model
"Calc Qty Act Matl, f() Rad Level"
Hot Matl Removal
Cat 1 - Reuse
Recond
Store
C/O
Cat 2 - Reuse
Reused or Recycle
Cat 3 - Warm
Cat 4 - Hot
Disposed
Determine Comp Dest based on Rad
Facil Disposal - Casks Approve
Hot Matl Removal Sequencing
Estab Hot Removal Process
Strip Out to Hot Blocks
Acquire Approvals
Clad Tungsten Plate Targets
Target Plate thickness
Cladding Process
Support Structure
Flow Distribution
Design Basis
Nominal flow
Min Flow for Switch Setting
Measurement System
Cooling Loop Pipe Size & Layout
Sup & Ret Header Design
Heat Exchangers
Pump Spec's
Filter Requirements
Pressure Control
Flow Control
Temperature Control
Measurement & Control
Safety Analysis
Off Normal Event
Safety Calculations
Required Doc's
Fuel Modules
Fuel Rod Support Structures
Outer Can for Fuel Temp Control
Flow Distribution
Cooling Systems
"Flow Design, Switch Settings"
Measurement Systems
Cooling Loop Pipe Design
Supply & Return Headers
Pump & Heat Exchangers
Filtration
Control & Measurement
Safety Analysis
Off Normal Event
Safety Calculations
Required Doc's
Matl Sample Tube Design
Matl Sample & Design Temps
Sample Temp Control
Flow Path Between Samples
Support Structure
Flow Distribution
"Flow Design, Switch Settings"
Measurement System
Water Cooling Loop Design
Supply & Return Headers
Pump & Heat Exchangers
Filtration
Control & Measurement
Safety Analysis
Off Normal Event
Safety Calculations
Required Doc's
Beamstop Design
Water Cooling Loop Design
Safety Analysis
Main Reflector Design
Water Cooling Loop Design
Safety Analysis
Secondary Cooling Requiremts
Cooling Design
Target Chamber Sealing
Split Target Beam Design
Raster
Folded Beam